Microlithographic Mask Development (MMD)

CDRL D004

Contractor Progress, Status, Management Report
1994 Annual Report

23 May 1995

Contract Number N00019-94-C-0035

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Loral Federal Systems Company, Manassas, Virginia

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Certification of Technical Data Conformity

The Contractor, Loral Federal Systems Company, hereby certifies that to the best of its knowledge and belief, the technical data delivered herewith under Contract Number N00019-94-C-0035 is complete, accurate, and complies with all requirements of the contract.

May 23, 1995
Date

[illegible] for S.G. Schnur
S.G. Schnur, Program Manager

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1.0 Introduction

This document, Contractor Progress, Status, Management Report, is submitted in accordance with CDRL D004 under contract N00019-94-C-0035 and covers the period 23 December 1993 through 23 December 1994.

Monthly Contractor Progress, Status, Management Reports have been submitted in accordance with CDRL D004. These reports have provided significant technical detail and insight into accomplishments and problems encountered during the past twelve months. This report does not cover the same information to the level of detail reported monthly but does review highlights, accomplishments and technology issues.

Program Summary

Engineering emphasis during this first year of the Microlithographic Mask Development (MMD) program was focused on establishing the manufacturing capability to fabricate prototype X-ray masks (XRM) and prototype phase shift masks (PSM) for delivery and use by the advanced lithography community.

This activity included not only the technical aspects of mask manufacturing such as process optimization, tool procurement and technology acquisition, but also involved the logistics and control systems required in a manufacturing environment, developing the technical plans to meet industry lithography requirements, establishing the support infrastructure for the mask technology, and establishing the business processes required to become a commercially viable enterprise.

During the first year of the MMD program, significant progress has been realized in all areas. At the same time, many extremely challenging technical issues have been identified and are being addressed as the X-ray and phase shift mask technologies are made ready for production. Progress and issues are addressed by task in this report.

It should be noted that in July, 1994, in response to industry requirements and needs, work was initiated to redefine the technical focus of this contract. As originally awarded, the mask technology followed what was thought at the time to be an aggressive evolutionary lithography generation expressed in terms of minimum mask feature, image size control, pattern placement control, defect density, inspection and repair, and pattern complexity. The original technology plans focused on 0.35μm technology during the first two contract years and then evolved to limited 0.25μm and 0.18μm generations. Input from industry clearly indicated that the MMD emphasis should be on generations at 0.25μm and beyond as optics would be the semiconductor manufacturing lithography strategy through 0.35μm and perhaps into the

0.25μm generations. A proposal that addressed industry concerns and closed on the Semiconductor Industry Association (SIA) Lithography Roadmap requirements was forwarded to the government for approval.

The remainder of this report addresses the re-phased program rather than the program as originally awarded. The re-phased proposal is significantly more challenging and aggressive than the original program.

2.0 Validation Study (Task 1)

***Task Objective:* Develop a pilot line validation study for the production of masks with test and/or circuit patterns that use 0.25μm and 0.18μm design rules.**

The first Validation Plan (CDRL C001) was submitted for initial approval on 21 April 1994 and has been revised three times per contractual requirements. The most recent update was the annual revision dated December 23, 1994. At the request of the customer, significant changes were made to this document to reflect the shift in emphasis to 0.25μm and 0.18μm mask fabrication technology. The overall targets requested by the customer are aggressive but are required to position the technology for manufacturing insertion.

2.1 Test Vehicle Description

2.1.1 EXPO

The test vehicle for 0.25μm technology prototype X-ray masks (code named EXPO) consists of a 0.25μm testsite and two 16Mb SRAM chips. The chips are approximately 29.6mm×11.3mm and are spaced about 7mm apart. The 0.25μm testsite is located between the two chips and contains arrays, proximity patterns, image placement indicators and process monitors. Three critical levels of the SRAM device are being used for the test vehicle: PC (polysilicon gate level), CA (contact), and M0 (first metallization). They are identified as EXPOPC, EXPOCA and EXPOM0, respectively.

While the critical dimensions are stressed and evaluated in the 0.25μm testsite, a complexity factor has been included in the form of two 16Mb SRAM chips to stress the data system and to provide a large critical area for image placement and defect learning. The "chip" is a modification of existing testsites and is designed to represent a typical SRAM design. It consists of 64×4 subarrays separated by typical sense amps and data buses between the rows. It contains master wordline drivers between subarray columns 32 and 33. The other subarrays are separated by a typical gap cell. The subarrays consist of 128 (wide) by 512 (high) cells, which are separated between columns 64 and 65 by local word line drivers. The 16Mb SRAM chip will be replaced with a 64Mb SRAM chip for the 0.25μm technology validation masks.

Masks are inspected for critical dimension control, image placement accuracy and defects and are compared to the appropriate mask specification.

Image size is measured in the array of the final mask. The sites are randomly spaced across the chip from top to bottom and right to left to ensure representative measurements. There are 48 measurements made in the SRAM chips (24/chip) and 48 measurements in the 0.25μm arrays (8/block). The testsite measurements are used for product disposition and the SRAM chip measurements are recorded to track product

improvement; both are used to compare 0.25μm performance versus 0.35μm performance.

There are over 500 image placement indicators in each chip, which provides excellent coverage for Product Specific Emulation (PSE). Additional image placement indicators are included in the mask area between the two chips. Product disposition will be performed based on approximately 300 measurements throughout the two chip areas. Not all of the >1000 placement indicators will be measured routinely, but they will be available for distortion studies.

Defect inspection will be based on a die-to-die comparison by the KLA SEMSpec at 90nm sensitivity. Early inspections will be performed at 120nm sensitivity while learning progresses to fewer and smaller defects. Only the SRAM areas will be inspected for defects.

Mask measurements will be compiled in a metrological package which will accompany each mask shipment.

A detailed description of EXPO is presented in CDRL C003, 0.25μm Test Pattern Description.

2.1.2 NIGHTHAWK

The test vehicle for 0.25μm technology X-ray defect learning/validation masks (code named NIGHTHAWK) is a 64Mb SRAM chip, 30.1mm×17.8mm in size. The chip kerf, or peripheral area, contains 0.18μm arrays, proximity patterns, image placement indicators and process monitors. In addition to demonstrating mask technology improvement, the test vehicle was designed to support X-ray lithographic development activity. Outboard X-ray stepper alignment marks are included on the masks for the Suss stepper. Inboard alignment marks can be easily added in the kerf area for use with the SVGL X-ray stepper. This will allow the critical level masks of the test vehicle to be used for overlay tests with actual X-ray exposures.

The 64Mb SRAM chip with six transistors per cell provides 0.25μm critical dimensions (CD) and the complexity required for the defect learning/validation phase of the 0.25μm X-ray mask validation study. The chip consists of 16×64 subarrays separated by typical sense amps and databuses between the columns. It contains master wordline drivers between subarray rows 32 and 33. The other subarrays are separated by a typical gap cell. The subarrays consist of 128×512 cells which are separated between rows 64 and 65 by local wordline drivers.

This complex design represents a typical SRAM and, as such, has several critical levels. The CA (contact) and M0 (first metallization) levels will be used for the validation study.

Masks are inspected for CD control and image placement accuracy and defects, and are compared to the appropriate mask specification. The NIGHTHAWK test vehicle consists of one 64Mb SRAM chip which meets the CD and complexity requirements for the 0.25μm technology defect learning/validation masks. The 64Mb SRAM chip also meets the complexity requirement for the 0.18μm technology prototype masks. The kerf images are not required for the 0.25μm validation study. They are designed to meet the 0.18μm prototype requirements and thus extend the scope of data collected from this test vehicle.

Image size is measured in the array of the final mask for the 0.25μm validation study. The sites are randomly spaced from top to bottom and left to right to obtain a representative sample of data. For the 0.18μm prototype masks, these measurements will be made in the 0.18μm array structures. Approximately 50 measurements are made of the mask CD. Additional measurements are recorded as needed by the process and lithography engineers to track improvements and analyze experimental results.

There are over 2,000 image placement indicators embedded in the chip area. These provide excellent coverage for image placement analysis, process-induced distortion studies and Product Specific Emulation corrections. Additional image placement measurement sites are included in the kerf area around the chip. Product disposition will be performed based on approximately 300 measurements. Not all of the more than 2000 image placement indicators will be measured routinely, but they will be available for additional engineering evaluations as needed.

The SRAM chip was designed so that defect inspection could be performed as a die-to-die comparison of one half of the chip to the other half. Inspection will be performed using the KLA SEMSpec at 65nm sensitivity. Early inspections will be performed at 120nm sensitivity while CD control and image placement improve to allow inspection with greater sensitivity. Only the SRAM area will be inspected. For the 0.25μm technology defect learning/validation masks, no defects are allowed after repair.

Mask measurements will be compiled in a metrological data package which will accompany each mask shipment.

A detailed description of the NIGHTHAWK test vehicle is presented in MMD CDRL C003, 0.25μm Validation Test Pattern Description dated 09 December 1994.

2.2 EXPO Data

Many EXPO masks have been patterned during the second half of 1994 to support technology learning and meet contract deliverable requirements. These masks were patterned on both 50keV and 75keV mask writers using TNS and PMMA positive tone resists and Shipley negative tone resist. All masks were patterned using proximity corrected data. The M0 and PC levels were patterned using positive resist; the CA

level was patterned using negative resist. The masks were measured for image size control (I/S) of 0.25μm and 0.35μm images. The image size measurement results are shown in Figure 1 for the M0 layer and Figure 2 for the CA layer.

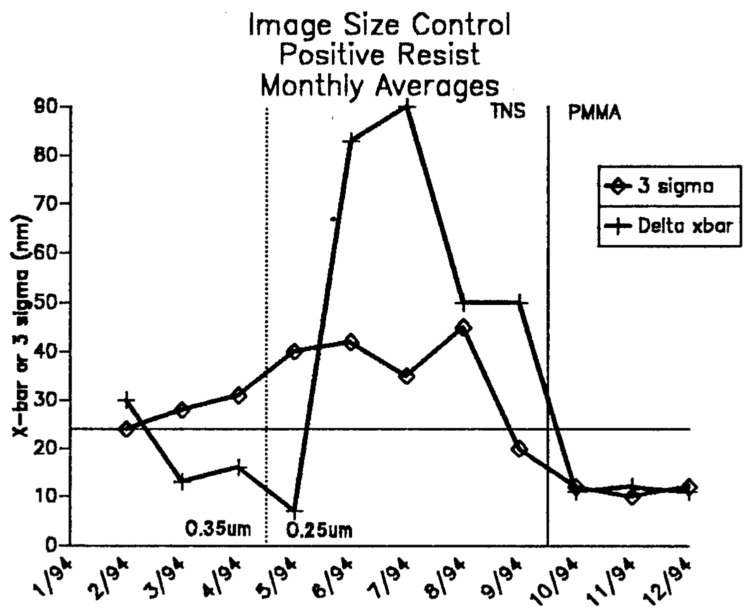

Figure 1. Image Size Control of TNS then PMMA Positive Resists

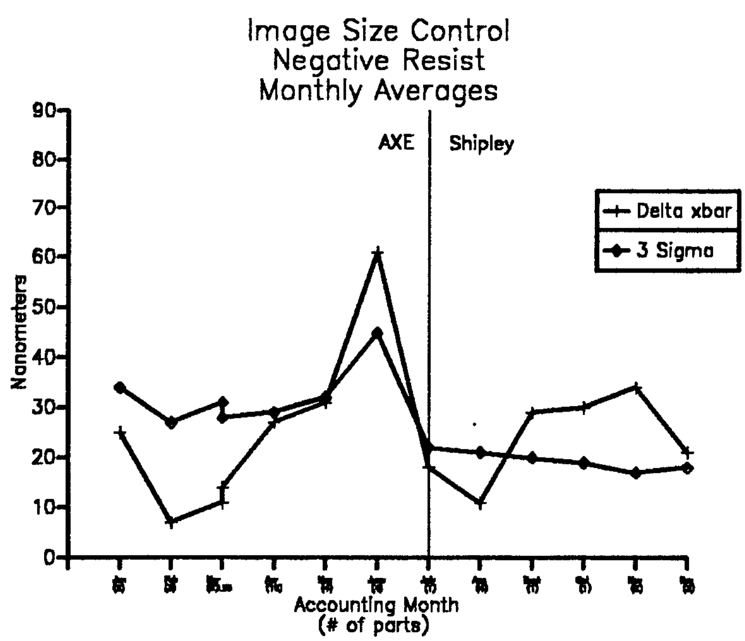

Figure 2. Image Size Control of AXE then Shipley XP Negative Resists

The image size control is excellent as shown in the measurement charts, Figure 1 and Figure 2. This CD control performance is the result of engineering efforts in all aspects of lithography during this first year of the MMD program. Photoresist materials have been evaluated and the most promising have been selected for use in patterning this generation of X-ray masks. The e-beam patterning tools have been characterized and tool controls have been improved to ensure that the tool contribution to the image size control error budget is minimized. Proximity effect correction factors have been experimentally determined and implemented to ensure linewidth linearity among various types and sizes of mask features. The resist processes - apply, bake and develop - have been optimized to improve both the delta from nominal performance as well as the 3σ variation on $0.25\mu m$ features.

Parts were also measured for final mask pattern placement. Data from these measurements are shown in Figure 3, Figure 4, Figure 5 and Figure 6. The data is plotted by mask level and by patterning tool. The image placement performance on the 50keV system has been improving. This system has been on-line since 1989 and extensive engineering effort has been invested to characterize the image placement performance and develop operational and hardware upgrades to minimize its contribution to image placement error. The 75keV tool has not received the same degree of optimization as efforts have focused on imaging at the higher accelerating potential and repairing a recurring vacuum problem. The I/P performance from this system is in the 100nm range versus the 60nm range from the 50keV system. This is discussed in Section 4.0 of this report.

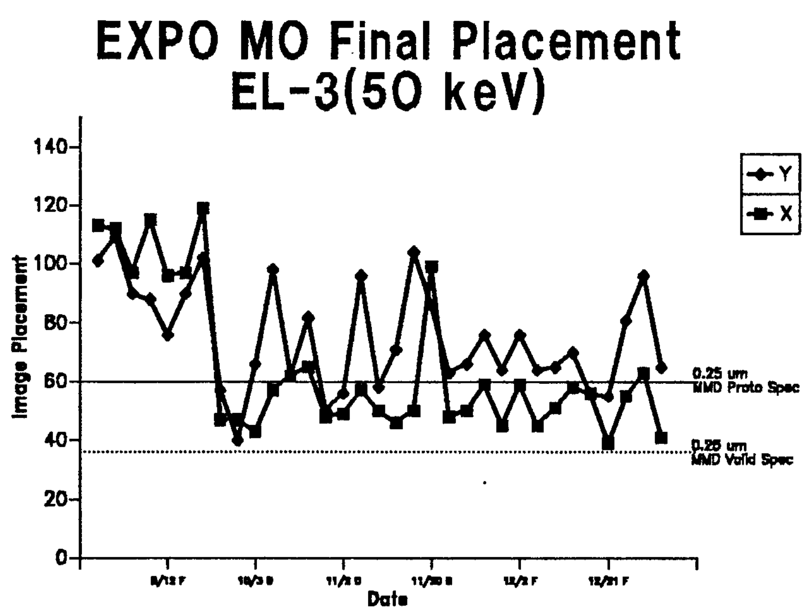

Figure 3. Final Placement Accuracy of EXPO M0 Masks Written on EL-3+ (#6)

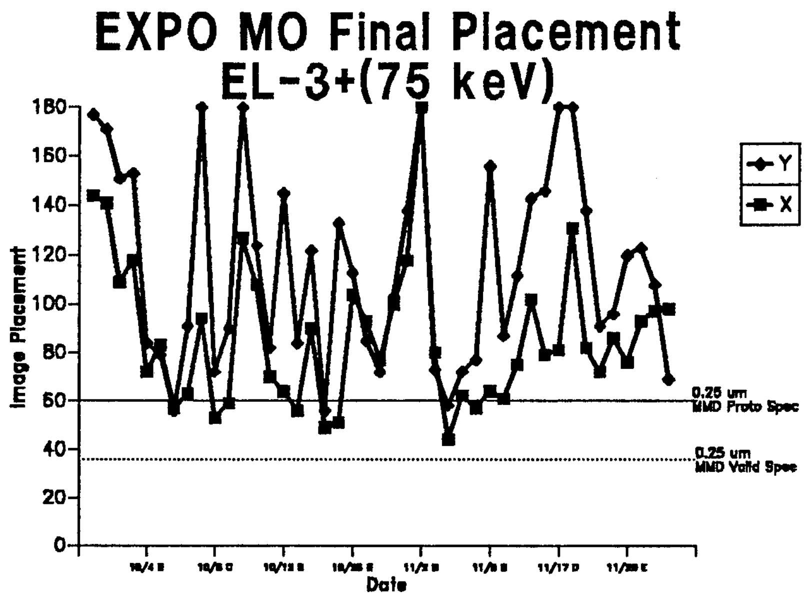

Figure 4. Final Placement Accuracy of EXPO M0 Masks Written on EL-3+ (#12)

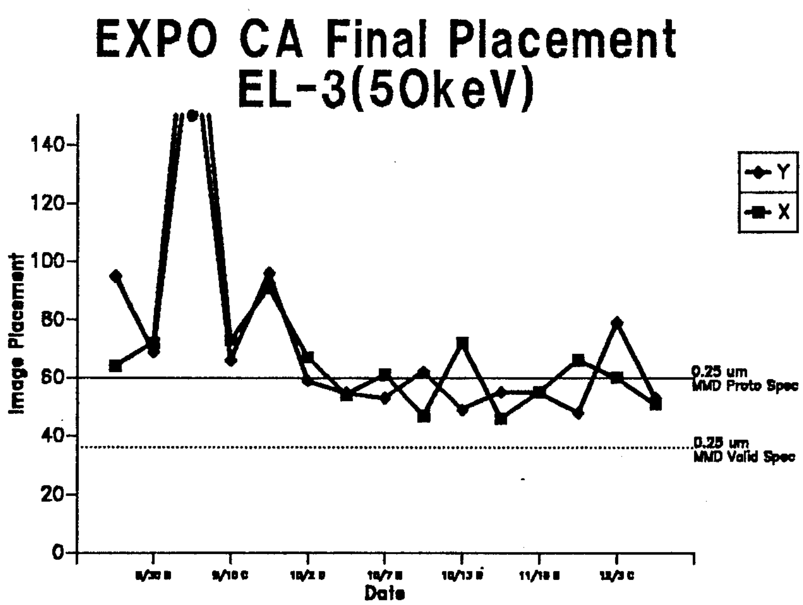

Figure 5. Final Placement Accuracy of EXPO CA Masks Written on EL-3+ (#6)

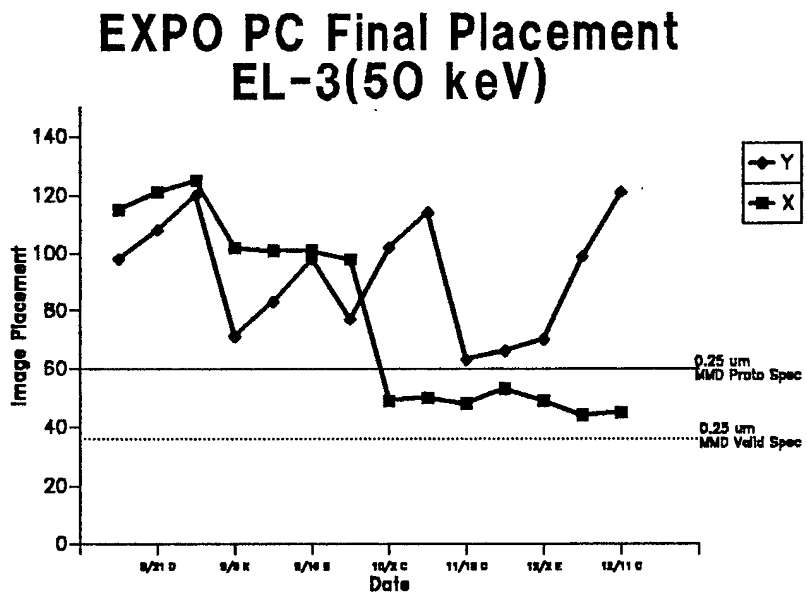

Figure 6. Final Placement Accuracy of EXPO PC Masks Written on EL-3+ (#6)

Inspection results on the EXPO masks that were fabricated are shown in Figure 7, Figure 8, Figure 9 and Figure 10. The defect density reduction team has chosen to monitor the performance of their activities with these charts which show the defect density before repair (Pre-Repair), after the actual repair (Post-Repair) and an engineering judgement of the defect density with repair for those masks which are not completely repaired due to time constraints (Eng Judgement-Repair). Numerous process and tool problems have had a negative impact on the defect density performance of these EXPO masks. Consequently, at this early stage in the deliverable ramp-up the masks have too many defects to be considered feasible candidates for repair; the lack of post-repair data reflects this. Teams have been formed to identify and eliminate the contributors to the high defect density results.

2.3 NIGHTHAWK Data

As previously discussed, NIGHTHAWK will be the 0.25μm defect learning/validation vehicle. Design and documentation work are complete on both the M0 and CA levels. These levels have been post-processed for the EL-3 and EL-4 patterning systems. Data verification masks have been patterned and successfully inspected. NIGHTHAWK will be routinely patterned and processed to meet validation and delivery requirements.

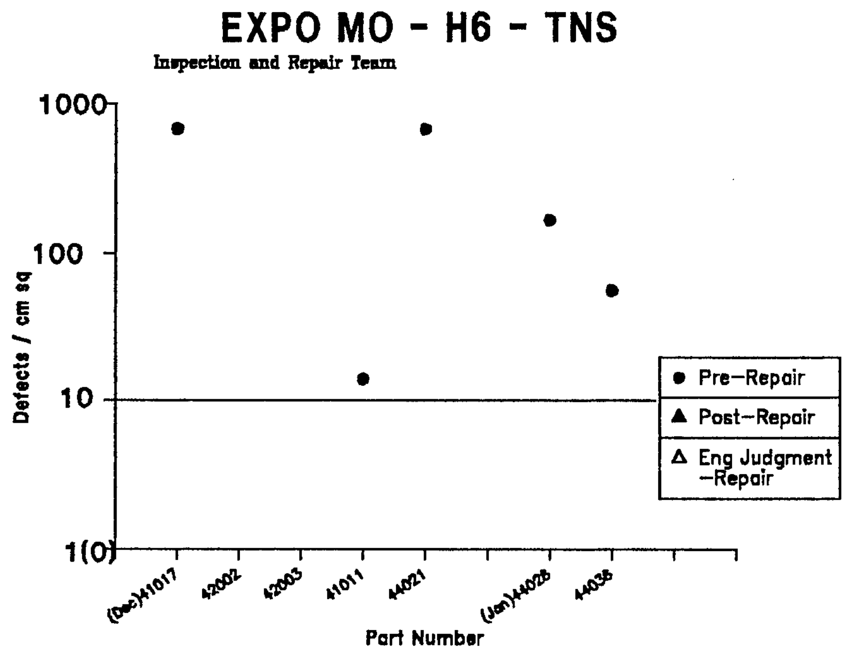

Figure 7. Defect Density of EXPO M0 Masks Written on EL-3+ (#6)

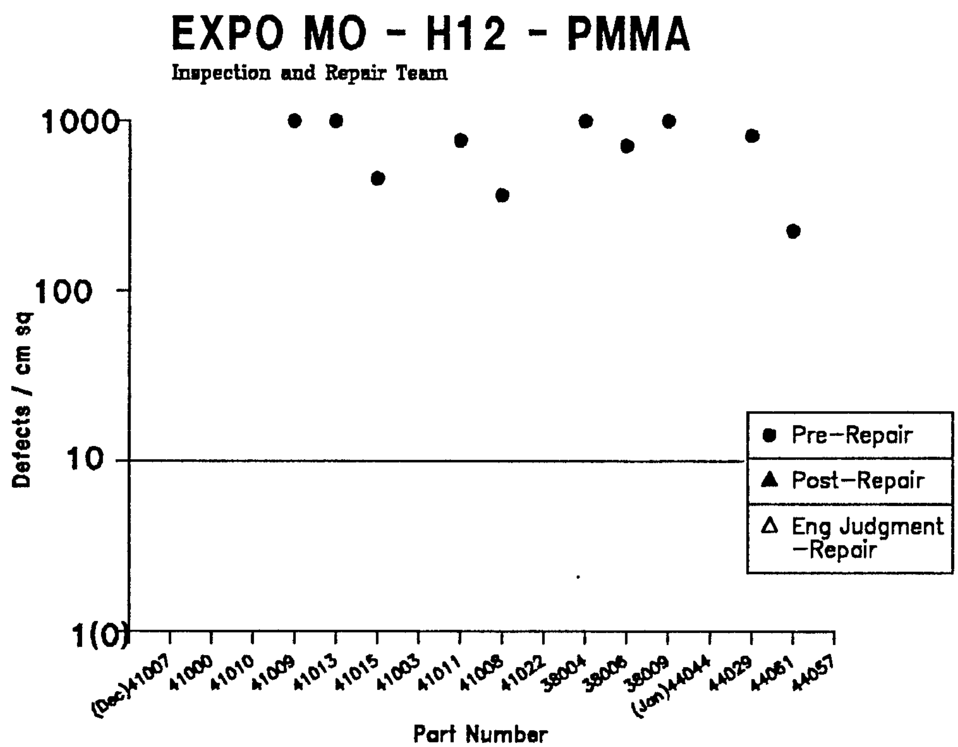

Figure 8. Defect Density of EXPO M0 Masks Written on EL-3+ (#12)

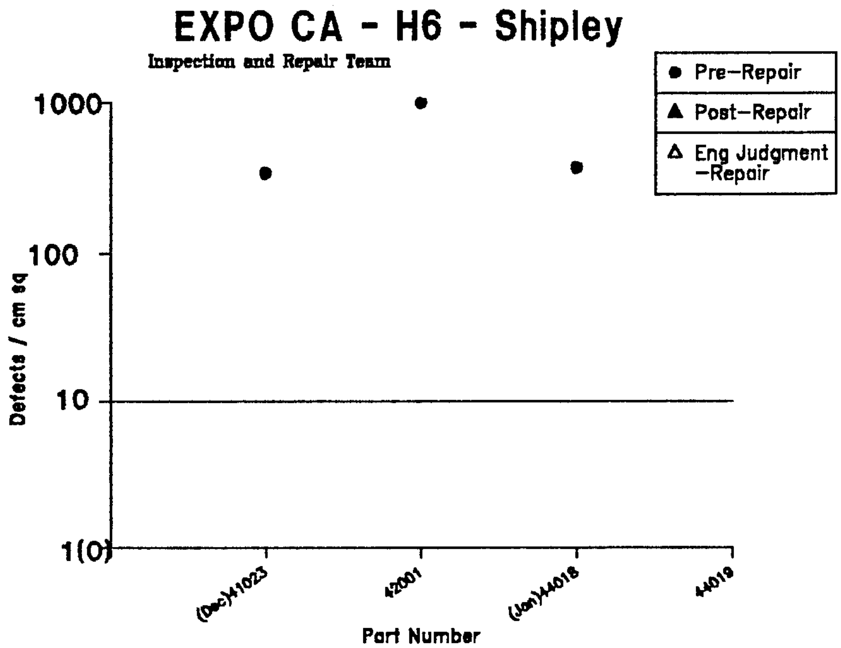

Figure 9. Defect Density of EXPO CA Masks Written on EL-3+ (#6)

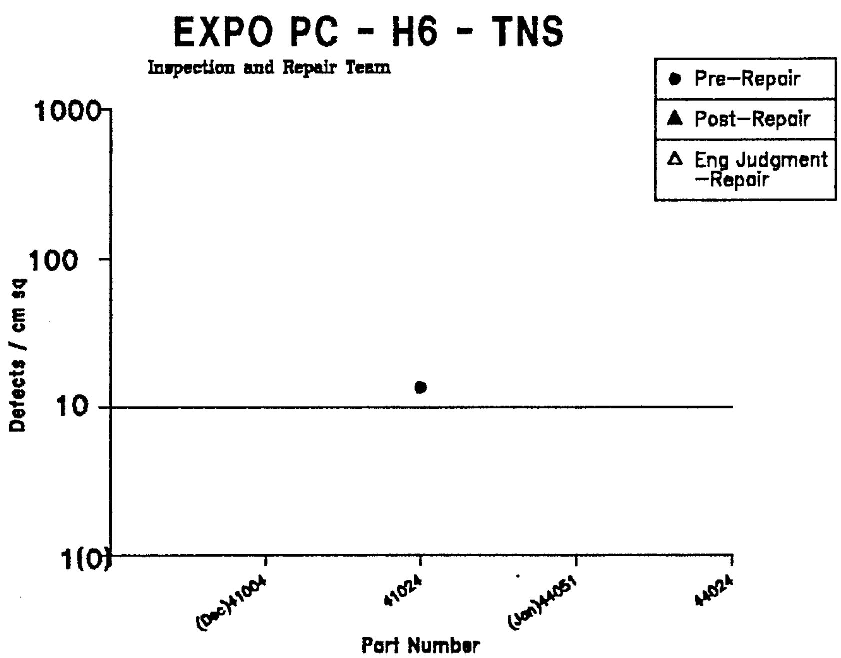

Figure 10. Defect Density of EXPO PC Masks Written on EL-3+ (#6)

3.0 Technology Roadmap (Task 1)

Task Objective: ***Devise a comprehensive MMD technology roadmap.***

The Technology Roadmap, CDRL C002, describes the processes, tooling and methodologies required to develop and demonstrate successive generations of X-ray mask fabrication capability. It includes a basic description of the processes and tooling currently in use for X-ray mask manufacture and detailed plans for the production of next generation X-ray masks.

The first Technology Roadmap was submitted for initial approval on 23 March 1994 and has been revised three times per contractual requirements. The first two updates were published prior to the 0.25μm System Design Reviews on 29 May and 25 July 1994. The most recent update was the annual revision dated 23 December 1994. At the request of the customer, significant changes were made to this document to reflect the shift in emphasis to 0.25μm and 0.18μm mask fabrication technology. The overall targets requested by the customer are aggressive but are required to position the technology for manufacturing insertion.

The changes made to the Technology Roadmap serve to ensure that X-ray mask technology matches industry requirements as defined by the Semiconductor Industry Association (SIA) in the National Technology Roadmap for Semiconductors. The main areas of concentration include critical dimension control, image placement control, defect density reduction, materials development and manufacturability issues.

Typical plans in graphical form are shown in Figure 11, Figure 12 and Figure 13 for the critical parameters of image size control, image placement accuracy and defect yield versus inspection sensitivity, respectively. The type of activity needed to achieve these aggressive learning targets is shown in Figure 14 for defect density reduction. Similar plans have been generated for all critical tasks.

Critical-Dimension Control Learning Plan

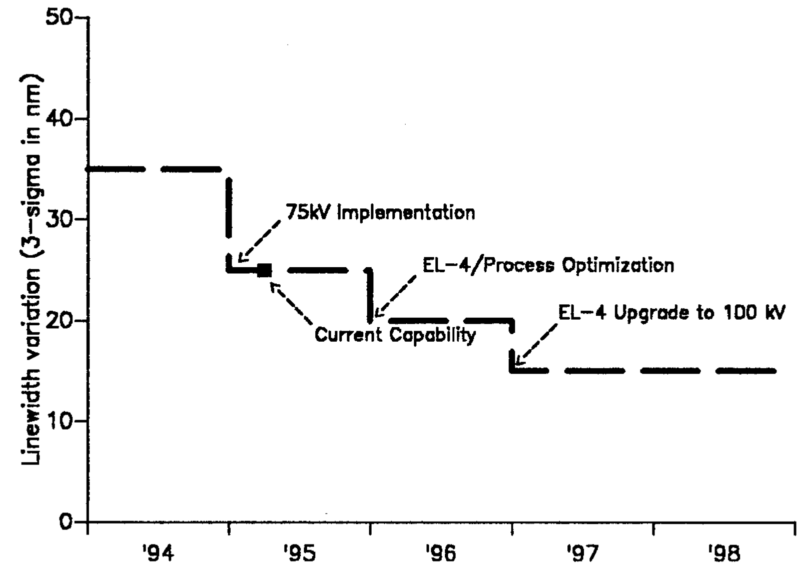

Figure 11. Critical Dimension Control Learning Plan

Final Mask Image Placement Learning Plan

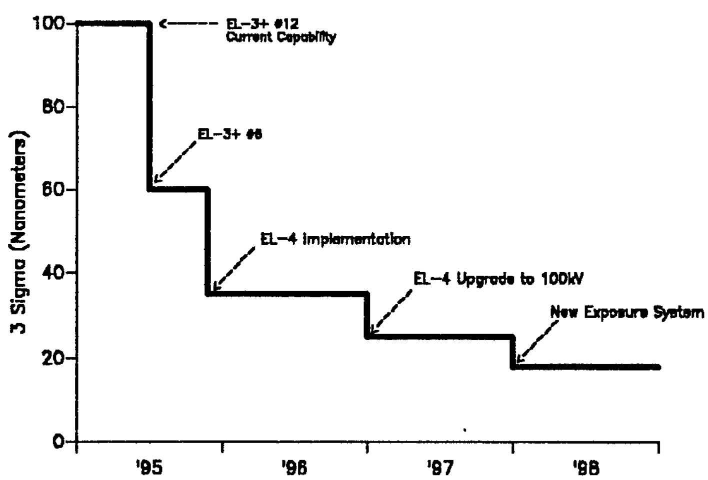

Figure 12. Final Mask Image Placement Learning Plan

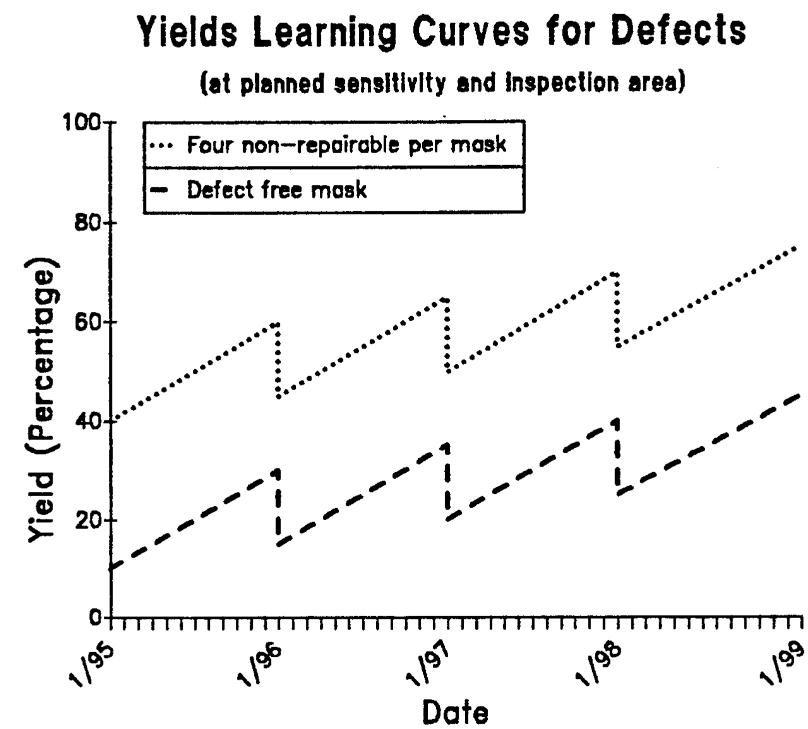

Figure 13. Yields Learning Curves for Defects (at planned sensitivity and inspection area)

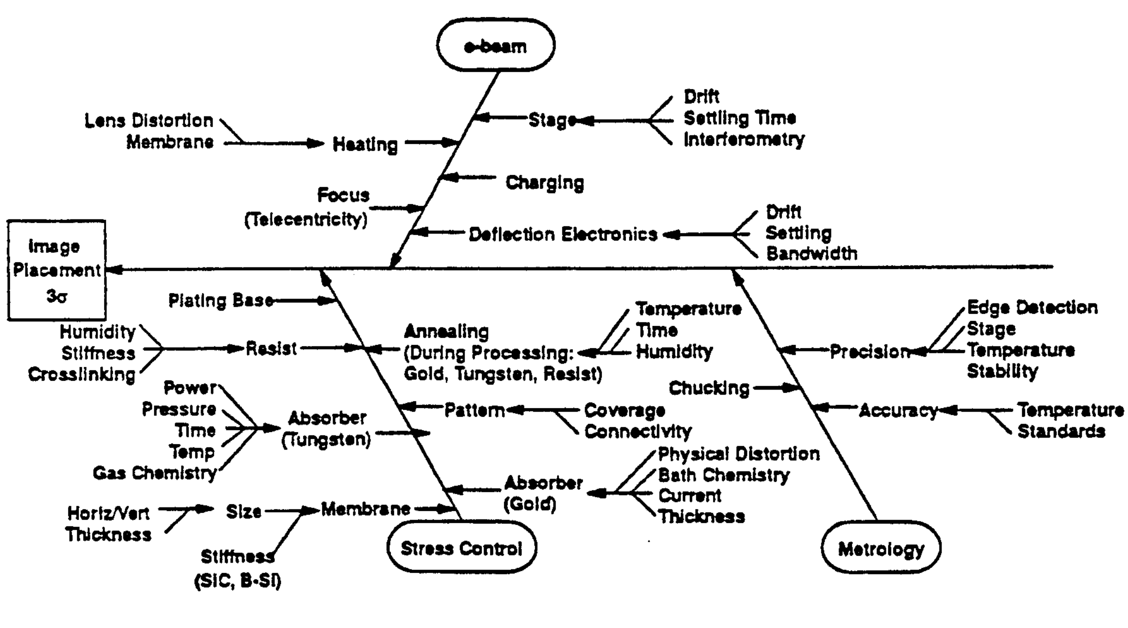

Figure 14. Defect Reduction Fishbone Chart

4.0 Develop and Demonstrate X-Ray Mask Fabrication Capability (Tasks 2 and 3)

Task Objective: ***Establish and maintain a pilot production facility capable of on-premises X-ray mask production, and demonstrate mask fabrication capability by fabricating prototype masks of increasing complexity.***

4.1 Line Status - Overview

A development line to fabricate X-ray masks was established prior to the award of the MMD contract with support from ARPA under DALP contract N00019-91-C-0207. The emphasis under MMD is to upgrade this established capability, moving toward a manufacturing environment where increasingly complex X-ray masks will be fabricated in volume to meet industry needs.

In general, line performance during the past year was good. Key tool availability was at or above target and there were no major facility problems impacting manufacturing or engineering activity.

As previously noted, the emphasis under MMD is to establish a manufacturing facility. Toward this objective, activity was initiated to implement the systems and controls to operate the fabrication line in a manufacturing mode. The use of Statistical Process Control has been expanded and control/action limits reverified. Manufacturing Control System (MCS) was implemented as the line logistics system. MCS has the capability to track product from sector to sector, generate yield and turn around time data, track process losses and set priorities. Mask fabrication processes and changes are controlled under Manufacturing Process Specifications (MPS) and Process Change Notices (PCN). These are generated on-line electronically, reviewed and approved. The documents are then automatically updated electronically.

The X-ray mask manufacturing quality plan was defined and documented in MMD CDRL A001, Quality Assurance Plan. This plan is based on the ISO 9001 certification requirements. The MMD facility was ISO certified in 1993. Semi-annual audits during 1994 indicate that compliance requirements continue to be met and the ISO Certification remains valid. Table 1 is a comparison of ISO 9001 requirements versus MIL-Q-9858A requirements, indicating that ISO requirements meet and in some sections exceed the MIL-Q-9858A coverage.

Table 1. ISO 9001 Requirements Mapping. Correlation of ISO 9001 elements with MIL-Q-9859A requirements.

ISO 9001 Section		MIL-Q-9858A Paragraph	
4.1	Management Responsibility	3.1	Organization
4.2	Quality System	1.3	Summary
4.3	Contract Review	3.2	Initial Quality Planning
4.4	Design Control	4.1	Drawings, Documentation and Changes
4.5	Document Control	N/A	
4.6	Purchasing	5	Control of Purchases
4.7	Purchaser Supplied Product	7.2	Government Property
4.8	Product Identification and Traceability	6.7	Indication of Inspection Status Traceability
4.9	Process Control	6.2	Production, Processing and Fabrication
4.10	Inspection and Testing	5.3	Completed Item Inspection and Testing
4.11	Inspection, Measuring and Test Equipment	4.2	Measuring and Testing Equipment
4.12	Inspection and Test Plans	6.7	Indication of Inspection Status Traceability
4.13	Control of Nonconforming Product	6.5	Nonconforming Material
4.14	Corrective Action	3.5	Corrective Action
4.15	Handling, Storage, Packaging and Delivery	8.4	Handling, Storage and Delivery
4.16	Quality Records	3.4	Records
4.17	Internal Quality Audits	N/A	
4.18	Training	N/A	
4.19	Servicing	N/A	
4.20	Statistical Techniques	N/A	

A mask order entry process has been defined and documented to ensure that X-ray mask orders are placed accurately and that the mask design/layout meets the user's needs. The process consists of two major phases. The first phase consists of a series of discussions between the MMD and the mask user. These discussions ensure the mask layout will meet user requirements, is compatible with the X-ray stepper and that there is agreement on specifications and delivery schedule. The second phase is the transmittal and preparation of the data for e-beam patterning. Modes of transmittal have been identified and verified during the course of the past year. Upon receipt, the data is processed through several software systems to convert to machine language and to verify that data integrity has been maintained. Significant improvements have been made during the past year to MMD's data handling processes through improved systems, streamlined procedures and experience gained with unusual orders.

4.2 Order Entry/Mask Data Preparation

As noted above, a mask order process and data preparation process have been defined and upgraded throughout the past year. These initial processes in the X-ray mask fabrication cycle are fundamental to the successful fabrication and application of the final mask. They are also extremely complex and technically challenging processes with little prior experience available as a base to build upon. The challenges in data handling have increased dramatically just in the first year of this contract. Data

volume has exploded four-fold with NIGHTHAWK having nearly 1.2 megabytes of data. Pattern density, another indicator of the magnitude of the mask challenge, has also grown dramatically. These challenges are depicted graphically in Figure 15 and Figure 16.

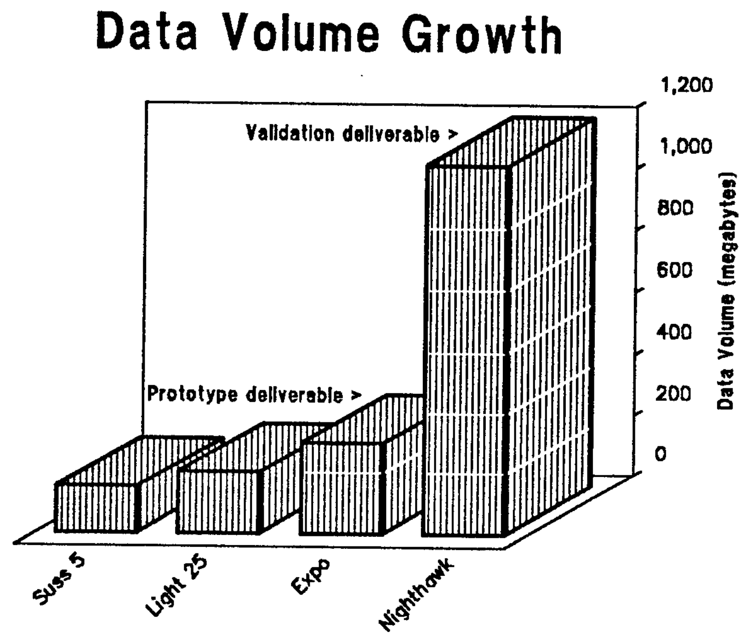

Figure 15. Data Volume Growth

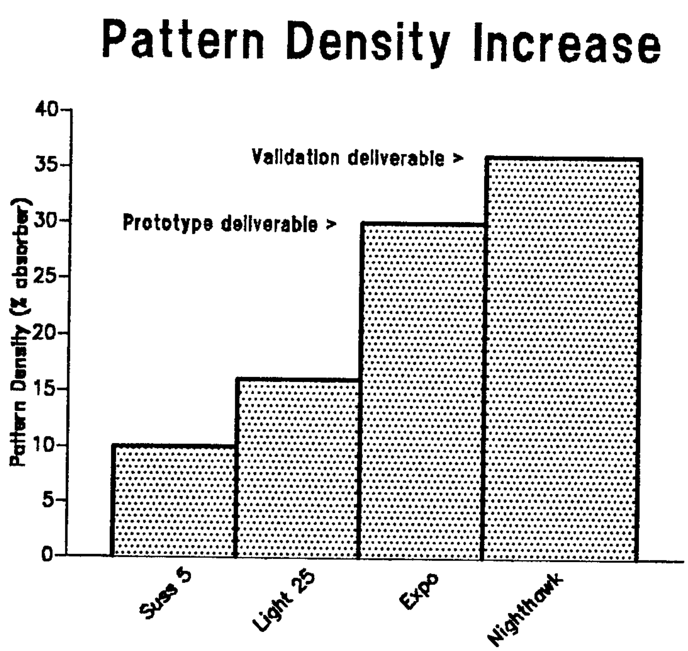

Figure 16. Pattern Density Increase

The mask order process consists of a series of design review meetings with the mask user, as well as the MMD mask fabrication team. These meetings address mask substrate requirements, mask layout, design issues and applications, specifications, and schedule and mask fabrication issues. The order process has been documented and results in a formal mask order released to the MMD manufacturing organization. Approximately 20 design review meetings were held during 1994, resulting in the release and build of X-ray masks for several major semiconductor manufacturers and universities. The MMD also provided design services to correct applications problems and assist mask users in finalizing their input designs.

The process and software required to translate design data to patterning tool data are complex and must operate without error. Significant improvements have been made during the past year to this data handling process. The actual process for handling design data in several formats has been documented and is under ISO 9001 control. A series of upgrades and enhancements have been planned to improve turnaround time, improve data handling efficiency, and to incorporate data verification at the system level.

This software and the data handling process is supported by systems analysts and engineers from IBM Burlington, IBM East Fishkill, IBM Research and commercial suppliers. Their efforts are focused on ensuring an error-free manufacturing system is in place to support X-ray lithography.

4.3 Front End of the Line Substrate Fabrication

During the past year, efforts in the front end of the line have focused on moving those sectors from a development environment to a controlled manufacturing line. This has entailed not only installing and upgrading the necessary controls but also focusing on manufacturing operations, cycle time, yield tracking and product quality.

As a result of this focus, high quality X-ray mask blanks are routinely produced for use in mask fabrication or for delivery to the X-ray community for development activities. Substrates are sorted based on inspection results with the lesser quality blanks used for experimentation or applications where defect levels are not a concern.

Product orders and their status in the line are summarized weekly and reviewed at the weekly team meeting. Substrate line deliveries with yield and turnaround time (TAT) for each order are summarized weekly for review.

The routine tracking of yield is shown in Figure 17. As shown in the yield trend chart, the MMD fabricator experienced a drop in Category A yield in November. The tracking and controls in place flagged the problem and allowed MMD engineering to identify corrective actions. The tracking procedures also highlighted the fact that

while initial efforts improved the yield somewhat, additional action was necessary. In fact, the yield/defect problems have proven to be difficult and teams are in place to identify the root cause of this yield impact and define corrective action. Details of this activity are reported in CDRL D004.

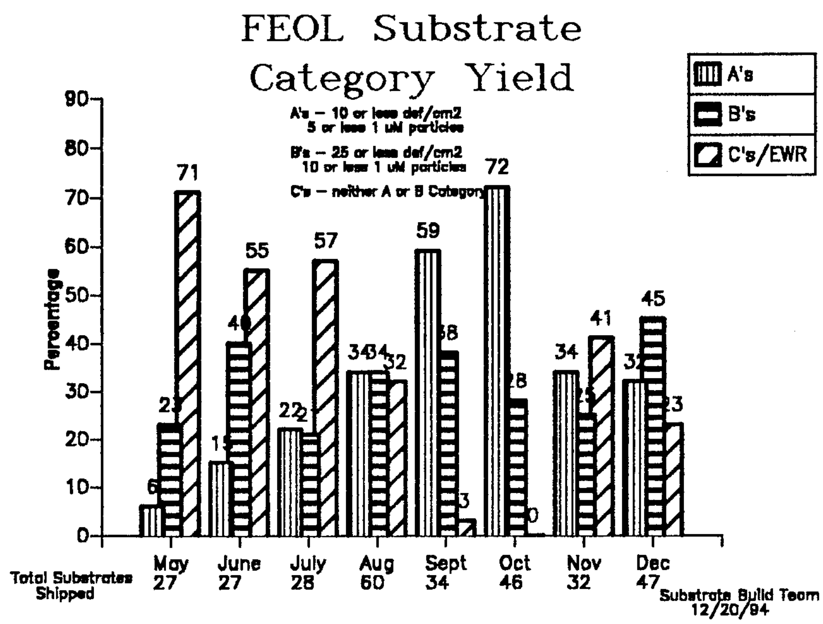

Figure 17. Substrate Fabrication Yield by Product Category. Category A has <10 defects/cm^2 and <5 defects larger than 1.0μm in size. Category B has <25 defects/cm^2 and <10 defects larger than 1.0μm in size. Category C has >25 defects/cm^2 or >10 defects larger than 1.0μm in size.

4.4 Lithography

Significant effort has been expended during the past year in the area of X-ray mask lithography and important improvements have been realized.

Specifically, engineering efforts have focused on photoresist material evaluation and selection, patterning system optimization, enhancement and control of related lithography processes (apply, bake, develop) and measurement of performance on completed X-ray masks. Dramatic improvements in image size control are illustrated in Figure 18 for positive resist and Figure 19 for negative resist.

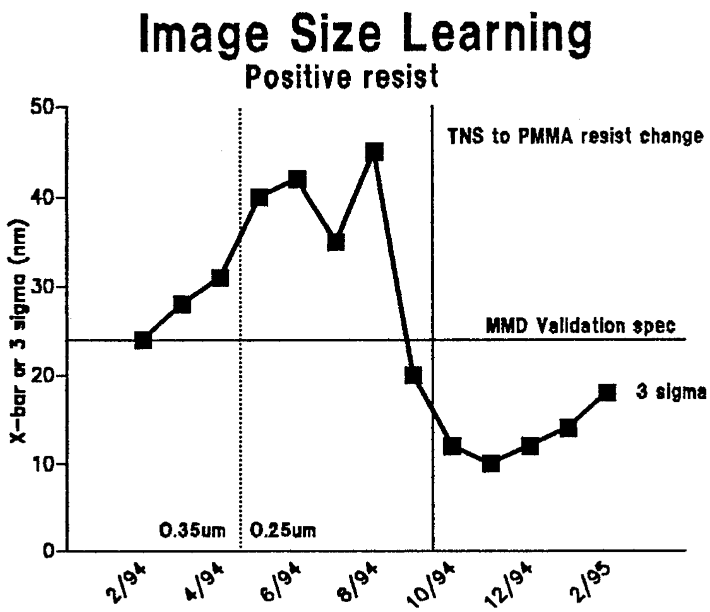

Figure 18. Image Size Control Learning on Positive Resists

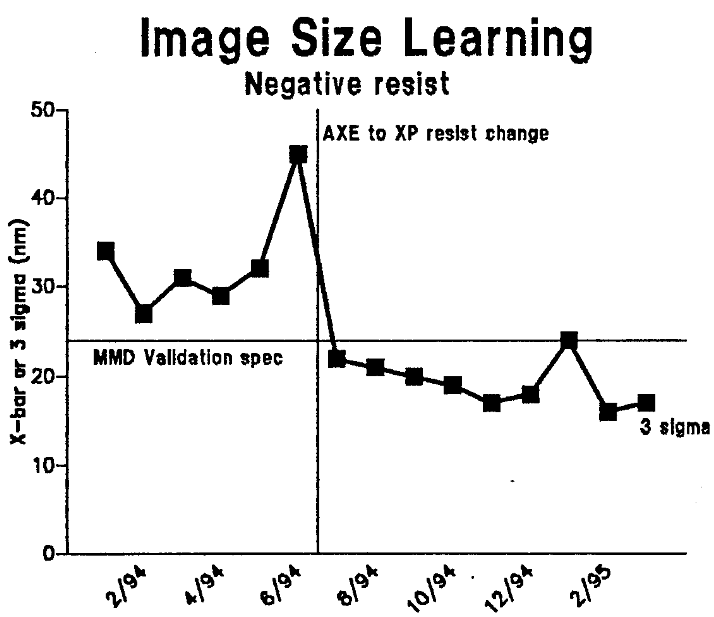

Figure 19. Image Size Control Learning on Negative Resists

4.5 Carbon Room

To enhance the stability of chemically amplified resists, a carefully controlled environment is required. The MMD has shown that not only are temperature and humidity important, but airborne chemical contaminants from distant sectors of the MMD facility can effect measurable changes in resist process behavior. These data are summarized in Figure 20. For effective process development of chemically amplified resists, a special room with carbon air filtration was justified and built. The room is currently 95% complete and will be ready for equipment installation early in January, 1995.

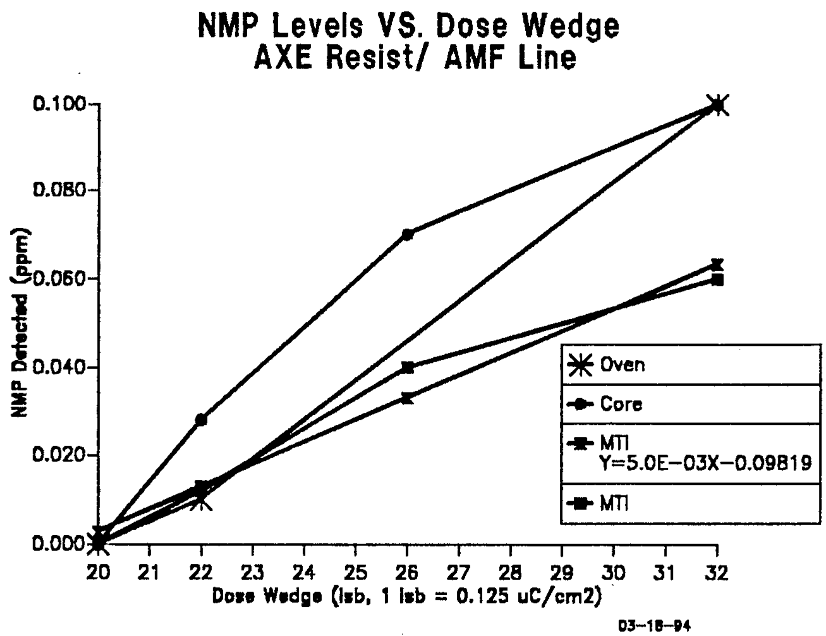

Figure 20. Airborne NMP Contamination Effects on Resist Develop Process

4.6 E-Beam Write Method Experiments with 64Mb DRAM Pattern

A variety of alternative e-beam writing schemes were investigated using a 64Mb DRAM pattern. These tests were aimed at assessing the impact of multi-pass, staggered-field and conductive topcoat schemes on image placement error. All of the techniques provided some improvement, with multi-pass (three passes) and staggered-field in conjunction producing the best result of approximately 40nm 3σ image placement error absolute to grid. The results are summarized in Figure 21.

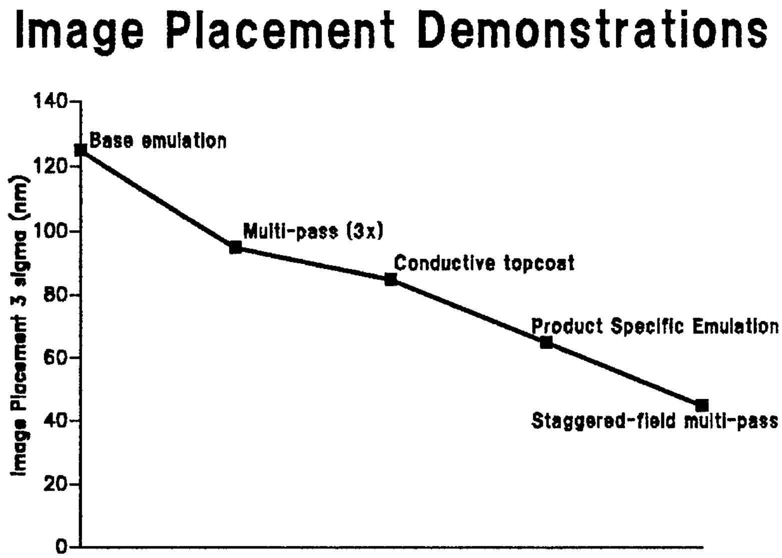

Figure 21. Image Placement Demonstrations with 64Mb DRAM Gate Level 0.35μm mask

4.7 AXE Resist Status

AXE resist was determined to be chemically unstable and, consequently, unable to produce repeatable results for effective process development. AXE resist development efforts were discontinued in favor of Shipley XP non-chemically amplified negative resist. This resist was qualified and implemented as the negative resist of record in July, 1994.

4.8 BEOL Improvements

The BEOL (back-end-of-line) has implemented numerous manufacturing measurements to track performance. A paperless online statistical process control system is used to collect engineering data on tool performance, such as foreign material monitoring. Action limits are established so that tools are not operated for product until the process monitors are within specifications.

A Pareto chart of process detractors is generated weekly and discussed at the BEOL team meeting; a sample chart from December, 1994 is shown in Figure 22. Process yield by resist type and turnaround time (TAT) is also generated and discussed weekly. An example of this is given in Table 2. Process yield is summarized and tracked monthly as shown in Figure 23.

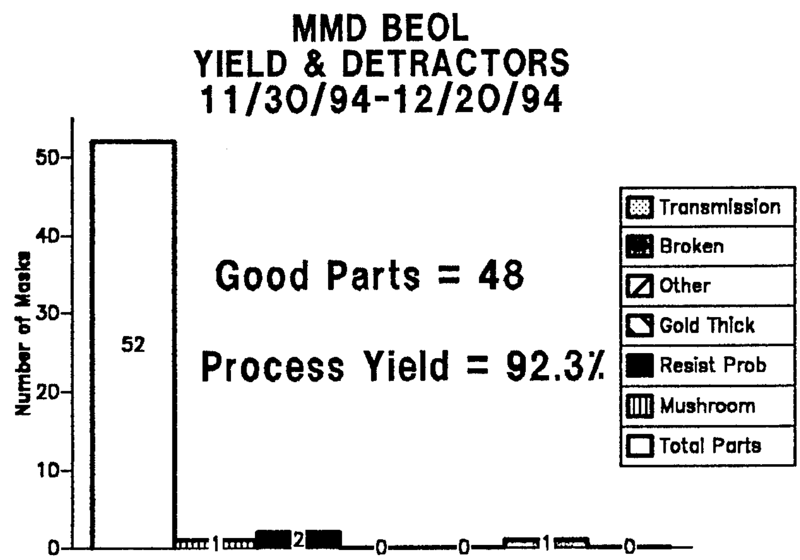

Figure 22. Sample BEOL Yield Detractors Pareto Chart

Table 2. Sample BEOL Process Yield by Resist Type for December

	TNS		Shipley		PMMA	
Week	% Yield	# Parts	% Yield	# Parts	% Yield	# Parts
11/30	*0.00*	*0.00*	*0.00*	*0.00*	*100.00*	*4.00*
12/08	*90.00*	*10.00*	*100.00*	*3.00*	*90.00*	*10.00*
12/15	*100.00*	*14.00*	*100.00*	*2.00*	*66.00*	*3.00*
12/20	*100.00*	*2.00*	*100.00*	*2.00*	*50.00*	*2.00*
12/27	*100.00*	*3.00*	*100.00*	*4.00*	*100.00*	*5.00*

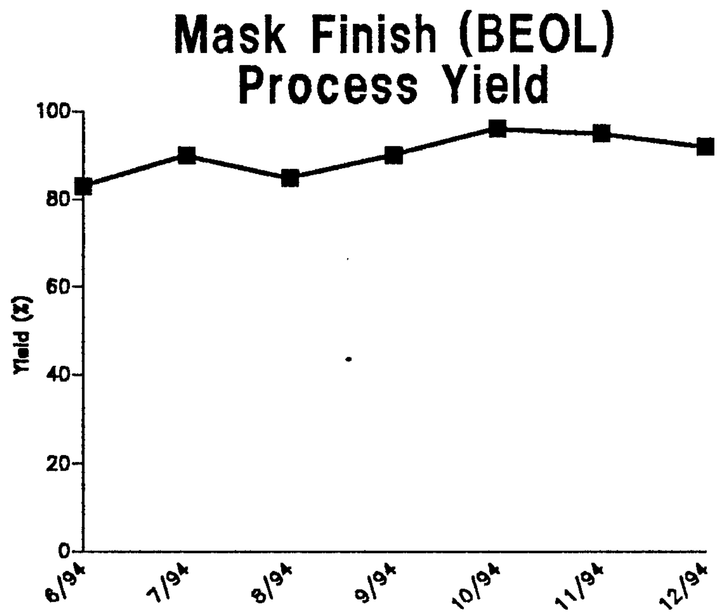

Figure 23. BEOL Process Yield Summary

4.9 Plasma Resist Strip

The use of helium-cooled plasma processing for X-ray mask fabrication was pioneered in the MMD. To leverage the success of this work further, a second tool with helium-cooling capability was justified, procured and qualified on 07 October 1994. The system is used for resist strip after gold absorber plating and complements the first system which is now dedicated to plating base removal. The availability of two tools allows dedicated processes and eliminates process cross-contamination. This results in improved quality and TAT.

5.0 Technology Acquisition (Task 8)

<u>Task Objective:</u> Evaluate the applicability and utility of new technology and tools to use in the MMD pilot production lines with the objective of improving production efficiency, quality and profitability, and achieving progressively smaller mask feature sizes.

5.1 Shipley Resist Status

Shipley XP negative resist was evaluated for e-beam patterning. This chemically amplified resist was shown to have superior stability, repeatability, resolution and image size control and was adopted and qualified as the negative resist-of-record in July, 1994.

5.2 PMMA Resist

PMMA positive resist was evaluated for e-beam patterning. This resist is well-characterized in the literature and offered significant advantages in linewidth control and resolution while being very repeatable and chemically stable. This resist was adopted and qualified as the positive resist-of-record. A complete report was published under CDRL C007, 19 December 1994.

5.3 Multiple Pass Exposures With Single and Multiple Skeletons

To meet the strategic goals for level-to-level overlay, the 3σ image placement on the mask is required to be in the sub-50nm region. In order to achieve this performance, new methods of patterning must be evaluated. The multiple-exposure e-beam writing method was originally documented by the Japanese researchers S.Aya, et al., in November, 1993. It consists of writing multiple passes at a coinciding fraction of the dose such that the integrated dose is correct. The passes may or may not be done with an offset imposed between field boundaries of each pass. A variation of the classical method was used for this evaluation since the EL-3+ system cannot easily change field and subfield sizes between passes. The experiment description and results are documented in CDRL C007, 14 October 1994.

5.4 MIT Tungsten Absorber Evaluation

The Massachusetts Institute of Technology (MIT) has developed a tungsten absorber deposition process which was evaluated for use in the MMD. The material was unsatisfactory in its high average stress and stress non-uniformity. MIT recognized these significant problems and has returned to process development to correct these fundamental shortfalls. No further characterization effort could be justified at this point in MIT's development. A complete report was published in CDRL C007, 14 October 1994.

5.5 Silicon Carbide Substrate Vendor Evaluation

An extensive evaluation of silicon carbide vendors was conducted including numerous material tests and demonstrations with some. The field was narrowed to three candidates based on technical considerations: Fujitsu, Hoya and Materials & Technologies. After a competitive bidding process, a contract to deliver silicon carbide membranes and substrates was awarded to Materials & Technologies. The vendor had a variety of process problems and was not able to deliver in accordance with the Statement of Work. Consequently, the contract was terminated due to non-performance. The overall silicon carbide insertion strategy is being re-evaluated at this juncture and a new Statement of Work is being developed.

A complete report on the initial contract was published in CDRL C007.

6.0 Technical Interchange Meetings (Task 10)

***Task Objective:* Conduct Technical Interchange Meetings for industry and the government on a bi-monthly basis.**

The Technical Interchange Meetings (TIM) listed below were held during 1994. A complete accounting of each meeting, including summary, action items and list of attendees, were submitted following each meeting in accordance with CDRL D002, Technical Interchange Meeting Minutes. Presentation materials were distributed at the meetings.

- MMD Kick-off Meeting

  This TIM was held on 23 February at Loral Federal Systems' Manassas, Virginia facility. Technical presentations were made reporting on LFS's plans and progress to date on the tasks funded under the MMD contract Statement-of-Work. Reference CDRL D002, 94-MMD-LFSC-00011, dated 09 March 1994.

- Design for Manufacturing Workshop

  This was the first of two TIMs on the subject of design for manufacturing. The meeting was held at IBM's Burlington, Vermont facility on 08 March. This workshop was intended as an open forum to address the technical issues embodied in the management of the various data formats and subsequent processing of that data for X-ray mask manufacturing. Each company represented at the meeting reported on their company's current data network, software and hardware, as well as the design practices 'traditionally' employed. Reference CDRL D002, 94-MMD-LFSC-00015, dated 25 March 1994.

- X-ray Mask Validation Plan and Roadmap

  This two-day TIM was held at IBM's East Fishkill, New York facility on 21 and 22 April. The 21 April session was devoted to technical presentations reporting on LFS's plans and progress to date under the contract Statement-of-Work. The second session, on 22 April, consisted of a four hour presentation on the Phase Shift Mask program plans and progress under the contract Statement-of-Work. Reference CDRL D002, 94-MMD-LFSC-00031, dated 06 May 1994.

- X-ray Design for Manufacturing Workshop II

  A TIM was held at Motorola in Austin, Texas on 24 June to address data issues; this was a follow up to the Design for Manufacturing Workshop held on 08 March in Burlington, Vermont. Presentations included summaries of updates and enhancements to the latest EL-3+ post-processor version and to the NIAGARA software. The remainder of the workshop was dedicated to "brainstorming" and outlining possible solutions to the rounding problem during conversion from GDSII to GL-1 data formats. Reference CDRL D002, 94-MMD-LFSC-00049, dated 11 July 1994.

- Optical and Phase Shift Mask Inspection

  This TIM was held at KLA in Santa Clara, California on 12 September and was a follow-up to a previous review that highlighted optical and phase shift mask inspection as an area where no closed plan exists for the 0.25μm and 0.35μm technologies. The main objectives of the meeting were to review current roadmaps and define projected capabilities for advanced COG and phase shift optical masks, to review industry requirements and gain concurrence on specifications/timing, to identify areas of closure and non-closure, and to make recommendations and define follow-on activities. Reference CDRL D002, 94-MMD-LFSC-00067, dated 05 October 1994.

- Die-to-Database Inspection Requirements

  The purpose of this TIM was to discuss industry requirements for an advanced die-to-database inspection of X-ray masks, advanced chrome masks and phase shift masks. The meeting was held at KLA's Santa Clara, California facility on 13 September. Reference CDRL D002, 94M-MMD-LFSC-00070, dated 06 October 1994.

- MMD Executive Review

  This meeting was a half-day TIM on 03 November at IBM's Burlington, Vermont facility. It consisted of technical presentations reporting on Loral Federal Systems activities and status to date on the tasks funded under the contract Statement-of-Work. Reference CDRL D002, 94-MMD-LFSC-00078, dated 14 November 1994.

7.0 Phase Shift Mask Activities

7.1 0.35μm Phase Shift Optical Mask Fabrication (Task 5)

__Task Objective:__ ***Demonstrate fabrication of 0.35μm phase shift optical masks.***

Primary activities for this task are focused on developing and implementing I-line attenuated phase shift mask (PSM) technology utilizing embedded shifter materials. Secondary focus is on developing the alternating/phase edge PSM technology.

7.1.1 0.35μm Technology Mask Deliveries

A total of fifteen 0.35μm technology I-line attenuated phase shift masks have been delivered, which include three thin chrome/etched quartz masks and 12 embedded chrome masks. Complete migration to the embedded process has been completed and future masks will be fabricated with this embedded technology. The product delivery masks were fabricated using a 0.35μm test pattern that was designed specifically for the phase shift technology. A full description of this test pattern was provided in CDRL C003. All image size, image placement and phase parameter specifications have been met. Defect learning has been recognized, and two of the most recent deliveries have had zero detected defects to a 0.50μm specification. For complete summaries, the mask metrology data packages can be referenced.

7.1.2 I-Line Embedded Shifter Development

I-line embedded shifter development has focused on chrome-based materials developed by Dupont under a Sematech contract. Early work focused on verification of the material and blank properties, and on establishing a specification for incoming blanks. Acceptable film uniformity has been demonstrated which is directly related to the transmission and phase properties of the blanks. UV stability testing has been completed, and no changes in the optical properties of the materials have been observed. The films have also been shown to be chemically stable. Specifications on transmission, phase angle and defect levels are now in place, and a sampling plan has been implemented to ensure conformance to these specifications.

A pilot line mask fabrication process has been established which consists of e-beam or CORE patterning, RIE etch, image size and image placement metrology, inspection, and laser repair. The e-beam process has been the process-of-record for approximately nine months. As the CORE was qualified, optimization of the CORE dose and the 895 i resist develop process have been the primary focuses. Acceptable image size and image placement results have been obtained from the CORE tool and defect analysis is underway.

Acceptable image quality has been achieved with the RIE etch processing. A previously developed alternative chemistry process has been evaluated and has shown

very good edge and sidewall quality with the CORE process. Plans are to implement this process for future mask builds.

Image size measurements have been qualified on the Siscan confocal system. SEM-to-Siscan correlations have been completed with the IBM Standards Laboratory and offsets have been determined. A unique measurement program has been set up on the Siscan, which includes this offset and optimized tool parameters. Image placement measurements are performed on the Leitz LMS 2000 system, with results comparable to standard chrome. Figure 24 and Figure 25 show image size and image placement performance for the 0.35μm MMD masks.

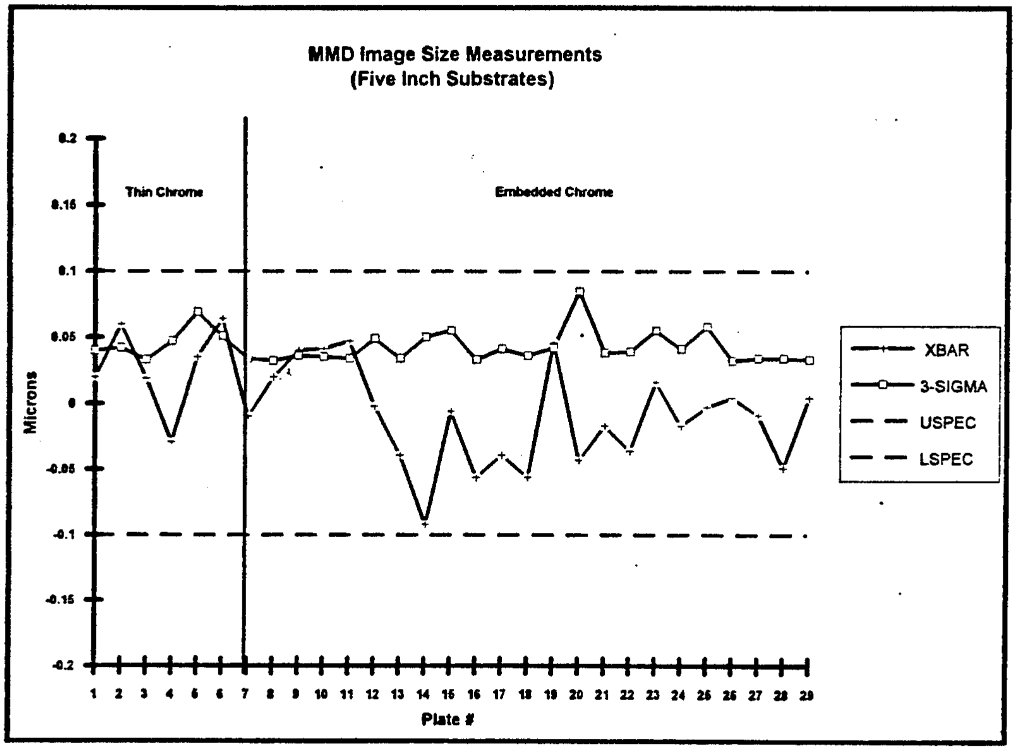

Figure 24. MMD Image Size Measurements (Five Inch Substrates)

Initial inspection evaluations were performed using the KLA 239 HR tool. Inconsistent results were obtained with pre-programmed defect masks and the focus was shifted to the KLA 331 tool. The KLA 331 tool has been qualified for embedded chrome inspection, which is currently performed to a 0.35μm criteria. Unique phase shift algorithms have been installed to allow light calibration for the attenuated films and also detection of transmission defects. Additional upgrades have also been installed to allow for improved sensitivity inspections.

The Quantronix laser repair process has been selected as the primary repair strategy, and laser power levels have been optimized for the embedded chrome films. An acceptable opaque repair process is in place but clear defect repair capability is minimal. The current tools have insufficient control of the chrome deposition process to allow for critical edge repairs. AIMS verification of these laser repair processes is

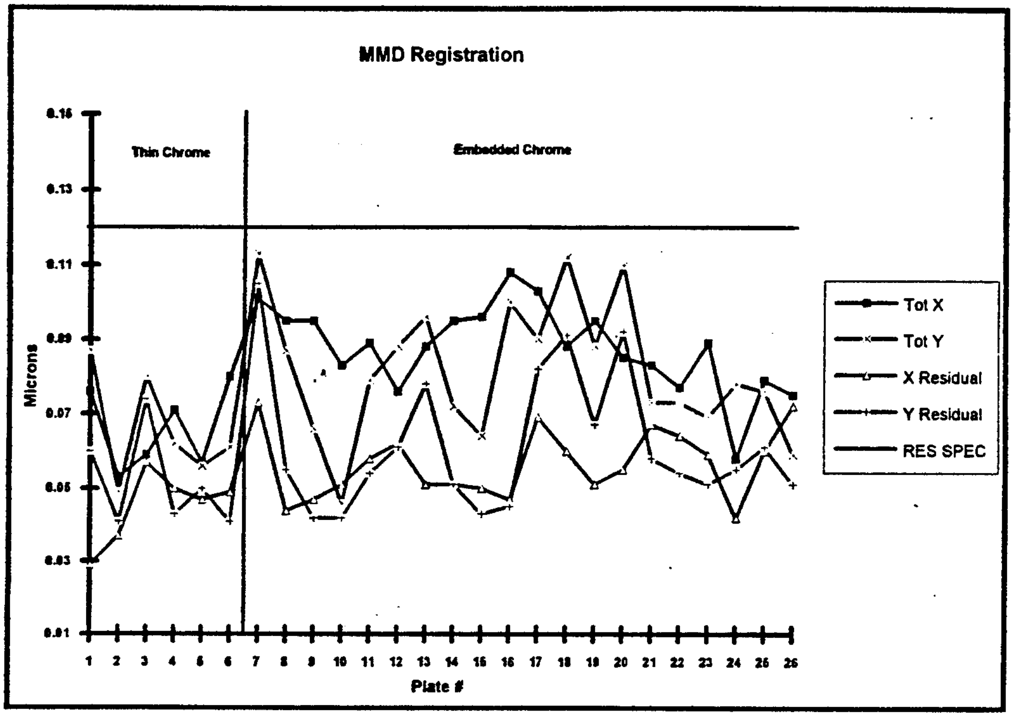

Figure 25. MMD Registration

currently underway. In addition, an advanced Quantronix DRS 3 laser repair tool has been ordered.

A large effort is focused on defect characterization and defect learning. Resist divots from the develop process were one of the initial defect types observed. Implementation of a develop pre-rinse eliminated this defect type. In addition to the divot defects, develop drying spots have also been observed. Modifications to the drying process have resulted in a reduction in the level of this defect type. A third defect type that has been identified is foreign material or residuals related to the resist strip and final clean process. A modified strip process has been implemented and an SSEC brush clean has been included also. These changes have lead to a significant reduction in the levels of these strip residuals, but additional work is still required. Clear defects are also observed, and although the incidence of this defect type is low, the majority of them are currently nonrepairable. Because of this, additional masks are rejected for clear defects with the e-beam process. The CORE process is expected to have a lower incidence of these defects and verification of this is underway. Figure 26 shows KLA 331 inspection results and post repair defect densities for the MMD masks.

Integration of an opaque border and alignment marks is also a key project. The initial strategy for this was to use a zero *E* field grating. Evaluations are in process, but aggressive tolerances may be required for production level masks. E-beam stripes have been observed, and large data volumes can lead to delays in fabrication of these gratings. Because of the problems observed, alternative approaches are being pursued.

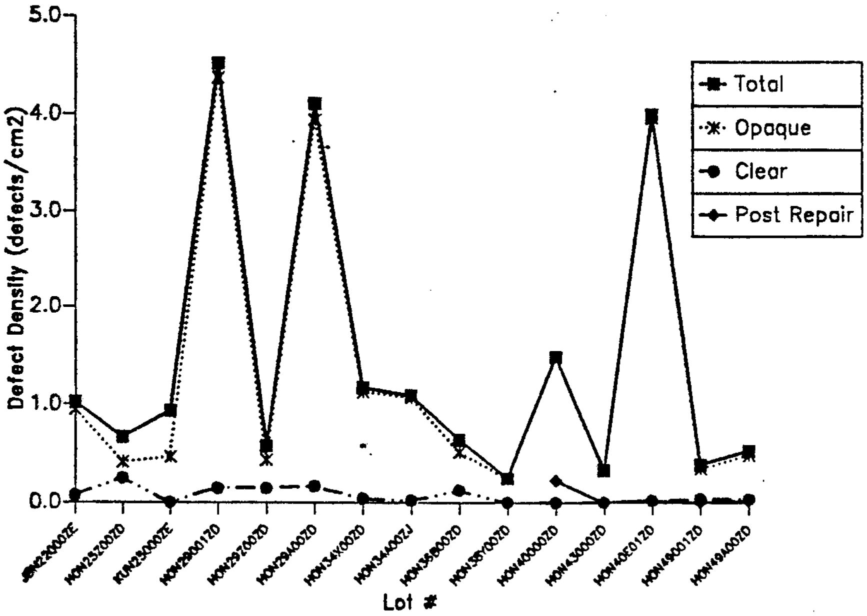

Figure 26. Embedded Chrome Defect Density Results (KLA 331 0.35 sensitivity/0.50 post-repair criteria)

7.1.3 Thin Chrome Attenuated Process

Initial mask deliveries were completed using the thin chrome/etched quartz technology, while the embedded shifter technology was being developed. A baseline patterning process was previously implemented which included metrology capability. Chrome level and phase level inspection capability was implemented in addition to a laser opaque repair process. A high level of defects was observed for the thin chrome process originating from the backside expose tool. Because the primary strategy was to migrate to the embedded shifter technology, no modifications or improvements to this tool were pursued. When the technology was converted to the embedded chrome technology, a significant reduction in defect levels was recognized.

7.1.4 Alternative Embedded Film Evaluations

I-line molybdenum silicide films, supplied by Hoya Corporation, were evaluated. The main potential advantage to these films is a more uniform optical transmission profile at higher wavelengths. A potential disadvantage is a lower etch selectivity between the embedded film and the quartz substrate. Blank samples showed acceptable film uniformity characteristics and pinhole and particulate defect levels that were comparable to standard chrome. UV stability testing was performed, and no significant changes in the optical properties of the films were observed. Chemical resistance testing showed a slight change in the film, which was likely an etching phenomenon. Additional chemical stability verification is required. DUV samples have also been received for analysis.

A baseline mask fabrication process was established which included e-beam patterning, RIE etching, inspection and laser repair. Acceptable image quality was observed and no appreciable quartz loss resulted during the RIE etching. Inspection and repair characteristics were comparable to or slightly improved over the embedded chrome technology.

7.2 0.25μm Phase Shift Optical Mask Fabrication (Task 6)

Task Objective: ***Demonstrate fabrication of 0.25μm phase shift optical masks.***

Primary activities for this task are focused on developing and implementing DUV attenuated technology utilizing thin chrome and embedded shifter materials. Development of alternating/phase edge technology is again the secondary focus. Similarities will exist in the efforts for 0.35 and 0.25μm technology development, although different materials and tighter specifications will be required for the 0.25μm DUV technology.

7.2.1 DUV Embedded Shifter Development

A carbon film developed by IBM Watson Research Center is the primary strategy for DUV embedded shifter development. Initial films were deposited with a PECVD system and physical and optical properties were verified. The films had acceptable phase and transmission properties and were chemically stable. A slight change in transmission was observed with DUV exposure but no phase angle change was observed. High stress levels were observed, however. A sputter process was then developed to be more compatible with industry deposition equipment. The current sputter films have similar optical properties to the PECVD films and have lower stress levels, but do not appear to be as optically stable or chemically resistant. DUV testing with a nitrogen ambient has been shown to form a stable environment for the films, so the current focus is on understanding the role of oxygen during DUV exposure. Alternative strip and clean chemistries are being evaluated to address the chemical resistance concerns. Potassium hydroxide and chromic nitric etchant have been shown to not attack the sputter films.

The current strategy for supply of these materials is to qualify a vendor to supply the blanks. Materials received from the IBM Yorktown deposition systems have been acceptable for film property verification and mask fabrication development, but they do not have sufficient uniformity or defect levels for production quality masks. Vendor discussions are underway with IBM Yorktown, and samples have been received for evaluation.

A baseline mask fabrication process is in place for the carbon embedded shifter materials. This process consists of CORE patterning with a metallic topcoat, RIE etching of the carbon, image size and image placement metrology, and laser repair. Early patterning evaluations focused on using resist as the etch mask and determining selectivity between the carbon and resist. Excessive resist erosion resulted and poor

carbon sidewall profiles were obtained. A previously developed metallic topcoat process was then implemented for use as an etch mask. Acceptable carbon profiles are now obtained with this process and biweekly control masks are now being fabricated.

Image size

Siscan-to-SEM correlations have been completed with the IBM Standards Laboratory. Offsets have been determined and these have been incorporated into the Siscan measurement programs. Standard Leitz LMS 2000 measurements are used for image placement.

Early inspection evaluations were performed using the KLA 239 HR tool. As with the embedded chrome, inconsistent results were obtained and focus shifted to the KLA 331 tool. Due to the inability of the 331 to do automatic light calibrations with the carbon films, no 331 carbon inspection capability currently exists. This is unique to the carbon film and other DUV films due to the high transmission characteristics at the KLA 331 488nm inspection wavelength. Samples have been delivered to KLA to resolve this, and a manual light calibration routine has been developed. Work continues on implementing an automatic routine. Blank inspection capability does exist, however, and these algorithms have been verified.

Integration of an opaque frame is also a requirement for the DUV technology. Due to extremely small images that would be required for a DUV grating, a dual level blank approach is being pursued. Evaluations were previously completed to demonstrate feasibility, and additional evaluations are underway.

7.3 General Phase Shift Mask Activities

Alternating/Phase Edge process control masks have been implemented on a biweekly frequency. The test pattern has been updated to include product type structures.

The CORE tool has been installed and qualified. Process control mask fabrication for the I-line and DUV embedded technologies have migrated to this tool. In addition, the two-level Alternating/Phase Edge mask fabrication process has been converted to the CORE. Significant improvements in process control and level-to-level overlay have been observed with this conversion of the two-level process. Final qualification of the embedded chrome CORE process is underway. (See 0.35μm Technology Development.)

The ALTA tool has been installed and final qualification is underway.

KLA 331 phase shift algorithms and upgrades have been implemented. The STARLIGHT upgrade purchase has been approved.

Specifications have been set for the Quantronix DRS 3 phase shift laser repair tool and an order has been placed. The current schedule for tool delivery has been delayed until 2Q95.

The AIMS tool has been purchased and installed. Final tool qualification is in process.

The APTCON develop tool has been installed and qualified. Phase shift mask evaluations are planned.

The Technology Roadmap and Validation Plan are in place. The 0.35μm System Design Review was completed.